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Application of Satellite Imagery
to the
Assessment and Exploitation
of
Oceanic Electromagnetic Ducting

by

Larry Francis Lewis

March 1981

Thesis Advisor: K. L. Davidson

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Application of Satellite Imagery

to the

Assessment and Exploitation

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Oceanic Electromagnetic Ducting

by

Larry Francis Lewis
Captain, United States Marine Corps
B.S., Southern Colorado State College, 1972

Submitted in partial fulfillment of the
requirements for a degree of

MASTER OF SCIENCE IN TELECOMMUNICATIONS SYSTEMS MANAGEMENT

From the
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March 1981

Author: Larry F Lewis

Approved by: Kenneth L Davidson
Thesis Advisor

Second Reader

Chairman, Department of Administrative Sciences

W M Woods
Dean of Information and Policy Sciences

ABSTRACT

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I. INTRODUCTION

Modern warfare is highly dependent upon the use of the electromagnetic spectrum for command and control communications, weapons guidance, and other electronics warfare support and countermeasures functions. Tactically essential systems are all affected by the meteorological environment in which they are operated. Operational enhancement or realized degradation in the performance of these electromagnetic systems by the environment must be a tactical concern of the task force commander who is employing them.

Decided tactical advantages will rest with the commander who is able to accurately assess and then tactically exploit the propagation characteristics of the lower atmosphere. The deployment of forces and modification of tactics based upon propagation considerations will, to the greatest extent possible, enhance the effectiveness of sensor, weapons, and communications systems.

This thesis describes the nature of the atmospheric refractive index, its possible effects upon the performance of electromagnetic systems, and the methodology available for the assessment of those effects. Constraints surrounding the assessment of ducting mechanisms, especially over large ocean areas, are addressed in the context of how satellite imagery may be used as a source of quantitative synoptic data to enhance the potential usefulness of the ducting environment.

II. BACKGROUND

A. THE ROLE OF ELECTROMAGNETIC COMBAT

When confronted by a threat environment, modern force commanders must be able to utilize their electromagnetic system assets as a force multiplier to counter enemy actions. Traditionally, electronic warfare assets of the force commander have been employed in operationally defensive modes revolving around self-protection tactics designed to enhance combat survivability of the task force elements. If the force commander's electronic warfare assets are included in an expanded doctrine of battle where there is integration of lethal and nonlethal systems in aggressive operational and support roles, then electronic warfare becomes offensive as well as defensive in nature.

The achievement of maximum effectiveness of intelligence exploitation, military deception, jamming, and platform guidance requires that the force commanders staff understand and be able to exploit the effects of atmospheric propagation variations upon their own electromagnetic assets as well as those of the enemy. Aircraft penetration profiles are now being selected on the basis of assessments of the atmosphere's affect upon the operational coverage of a search radar system. The same conditions can lead to command and control communications degradation or enhancement resulting in changing deployment schemes and EMCON conditions. Strategic positioning of critical mission aircraft to achieve maximum effectiveness could also depend on assessments of the propagation conditions present in the operational area.

B. VHF/UHF PROPAGATION CHARACTERISTICS

Most modern tactical systems operate in the very-high and ultra-high frequency range (VHF and UHF) of the electromagnetic spectrum. Since energy at these frequencies is not normally reflected by the ionosphere, variability in propagation depends upon the structure and composition of the lower atmosphere. Of particular interest is the distribution of water vapor and temperature with respect to height.

When VHF and higher frequencies were first put to use it was generally believed that propagation of the radiated wave was governed by the laws of diffraction of waves through a stable homogeneous atmosphere surrounding a spherical earth model.

While electromagnetic waves in the VHF and UHF portion of the spectrum experience the normal loss characteristics due to geometric scatter and diffraction, it has been shown that the effect of electromagnetic ducting produces the most dramatic impact upon the operational performance and effectiveness of a force commander's systems.

The smooth earth theory of radio wave propagation predicted exponential decreases of signal strength as one reached and went beyond the radio horizon. Mathematical solutions derived from this model predicted an exponential decrease in the signal strength level beyond the horizon of the earth of about 1.2 dB per mile at 500 mhz. Bullington [Ref. 1]. Thus the smooth earth model was a rather simple extension of the familiar concepts of directed and reflected ray modes based upon geometric optical paths.

As operational frequencies extended to higher ranges of the electromagnetic spectrum it became apparent that signals were frequently and consistantly being propagated far beyond the calculated radio horizon at strengths considerably greater than expected. This led to much closer attention being paid to the modifying effects of the atmosphere on the smooth earth propagation model.

C. THE ATMOSPHERIC REFRACTIVE INDEX

The atmospheric index of refraction is a function of temperature, humidity, and pressure. It is defined as the ratio of the velocity of propagation of the electromagnetic wave in a vacuum to that in air. Since at the earth's surface the numeric value of the refractive index is usually between 1.000250 and 1.000400 it is convenient to express the refractive index (n) as:

$$N=(n-1)\times 10^6 \tag{1}$$

hence producing a value of N of between 250 and 400 for the earth's surface.

Refractivity is related to atmospheric pressure, temperature, and humidity by the relationship:

$$N = \frac{77.6\ P}{T} + \frac{3.73 \times 10^5\ e}{T^2} \qquad (2)$$

where P is the pressure in millibars, T is the temperature in degrees Kelvin and e is the water vapor pressure in millibars.

Since both temperature and humidity normally decrease in a well-mixed standard atmosphere the normal value of N will also decrease with altitude, causing a radio wave of a sufficiently short wave length to be bent downward toward the earth's surface with a curvature less than that of the earth. If the air temperature increases with altitude or the humidity decreases abnormally rapidly, N will decrease with height much faster than normal. A high negative N value results in a wave being refracted downward with a curvature greater than that of the earth's curvature resulting in the formation of an atmospheric duct that causes the wave to be propagated over abnormally long distances.

III. ELECTROMAGNETIC REFRACTION AND THE ENVIRONMENT

A. PROPAGATION ANOMALIES

Climatological summaries of the atmospheric refractive index indicate that at sufficient height's above the surface the refractive index decreases linearly according to the standard atmospheric model. However, in the immediate neighborhood of the earth's surface there may be large deviations from the expected refractive index values. These deviations occur in atmospheric layers where the index of refraction decreases much more rapidly than in the standard atmospheric model. This condition causes electromagnetic energy of a sufficiently short wavelength to be trapped and propagated parallel to the earth's surface for great distances. This can result in abnormally high signal strength levels well beyond the system's normal operating range.

Since radar works on the principal of signal reflection, the atmospheric mechanism which causes the transmitted energy to be propagated to a target reflection point will also provide the return path for the echo signal to be propagated back to the emitter. One outcome is that anomalous refraction and, hence, anomalous return signals produce false interpretations of the actual target distance. Because the anomalous return signal is the result of atmospheric effects, the system will appear to be operating normally; as it is.

The atmospheric features associated with such modifications to the operating characteristics of VHF/UHF systems are known as propagation ducts. Ducts occur when atmospheric layers having extremely large negative gradients of refractivity form. These layers can exist because of abnormally rapid increases in air temperature and/or decreases of humidity with height. Such ducting mechanisms are most prevelent over ocean surfaces. Figure 1 is representative of the difference between the temperature and humidity gradients associated with a standard atmosphere and those which could produce a ducting mechanism.

A necessary consideration of ducted propagation is that a duct must have a minimum depth in order to trap specific frequencies. Table 1 is a summary of the thicknesses required in order for a ducting mechanism to trap energy of a specific wavelength.

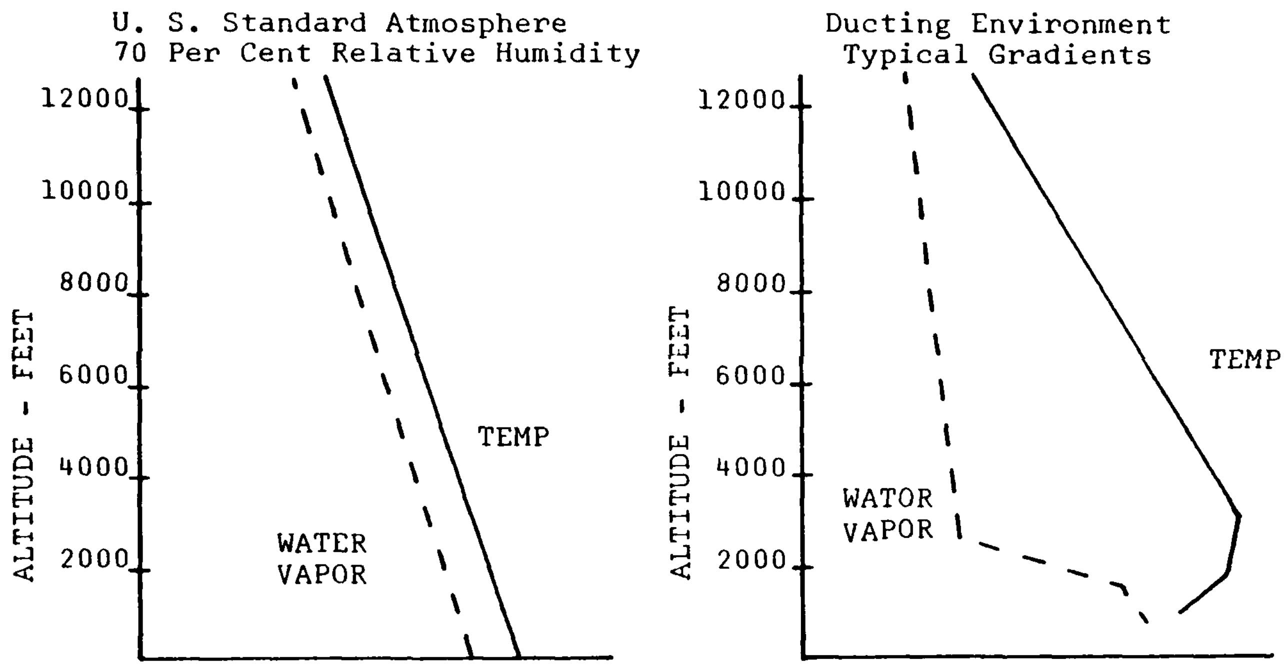

Fig. 1 REPRESENTATIVE TEMPERATURE AND HUMIDITY GRADIENTS.

Minimum Trapped Frequency (MHz) (Lower Cutoff) Frequency [LCOF])	Maximum Trapped Wavelength	Radar/Radio Band	Duct Thickness (Tt/m)
150	2.0 m	A (VHF)	587/179
192	1.56 m	A (VHF)	499/152
220	1.36 m	A (TAC UHF)	453/138
425	70.6 cm	B (TAC UHF)	294/89.6
1000	30 cm	D	166/50.6
3000	10 cm	F	80/24.3
5800	5.2 cm	G	51/15.6
8500	3.5 cm	I	40/12.2
9600	3.1 cm	I	37/11.2
10250	2.9 cm	J	35/10.7
15000	2 cm	J	27/8.3
30000	1 cm	K	17/5.24

TABLE 1. VARIATION OF MINIMUM TRAPPING FREQUENCY WITH DUCT THICKNESS.

1. Surface Based Duct

The elevated atmospheric layers containing critical temperature and/or humidity gradients can cause electromagnetic energy to be refracted back toward the earth's surface where it may be reflected back toward the refractive layer. Propagation of the wave over great distances occurs with the repetitive downward refraction by the sharp atmospheric gradient and the return reflection from the earth's surface. This process is termed a surface based duct since the earth's surface forms a portion of the ducting mechanism. (Figure 2a).

The distance over which a signal may be propagated by means of a surfaced based ducting mechanism is largely a function of how much energy is lost each time the wave is reflected from the earth's surface. Since water is a much more efficient reflection medium than land, ducting effects are generally more dramatic over ocean surfaces resulting in signals of near line of sight strengths being propagated several thousand miles beyond the systems expected operational range.

2. Elevated duct

At other times a refractive layer will form well above the earth's surface. This can result in an elevated duct which will trap and propagate energy as the surfaced based duct does. The difference between an elevated duct

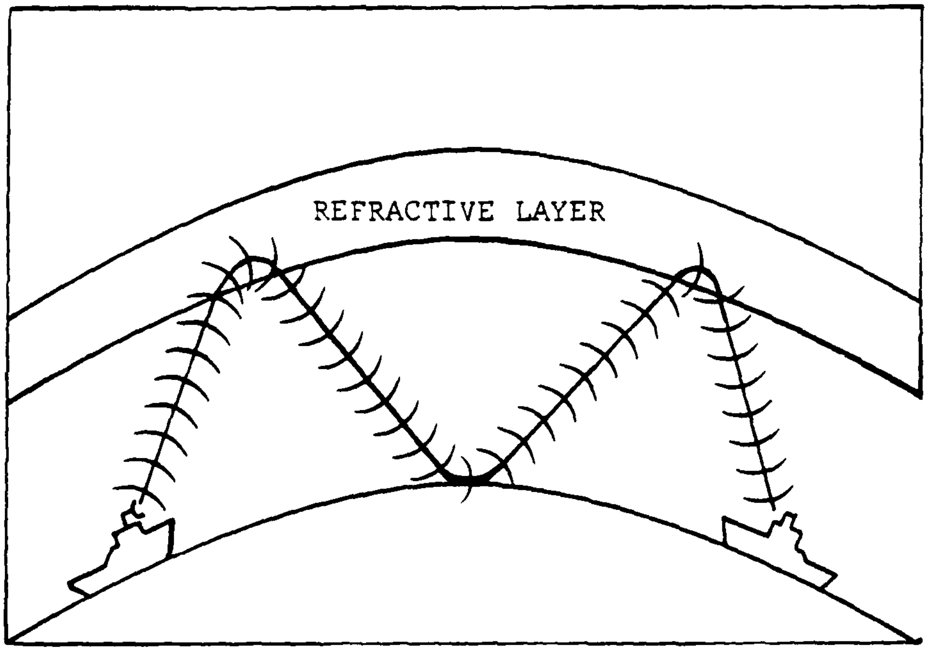

Figure 2a. SURFACE BASED DUCT.

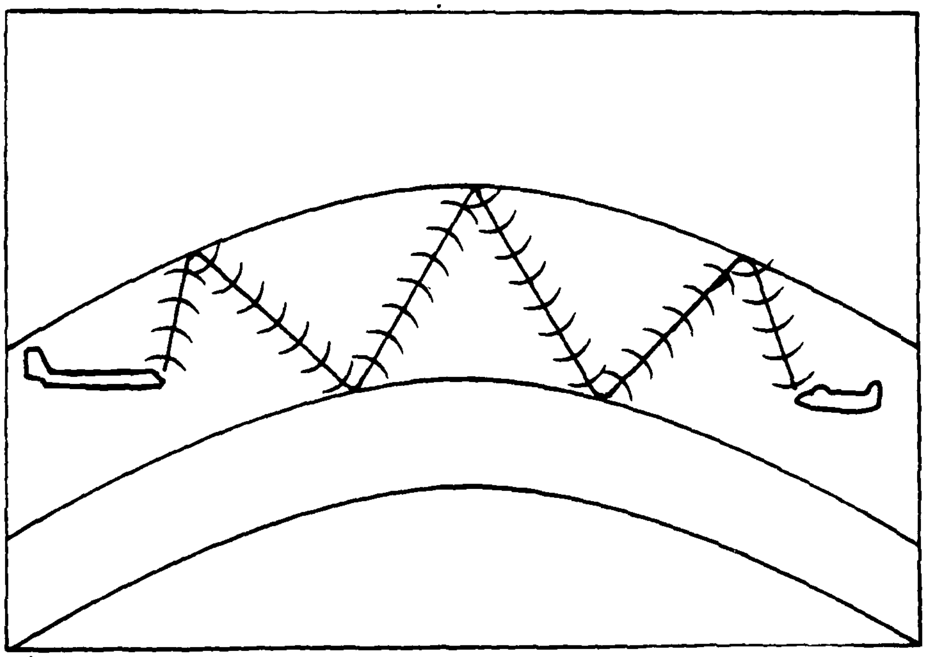
Figure 2b. ELEVATED DUCT.

and a surfaced based duct is that the wave energy in an elevated duct is reflected upward from the bottom of the refractive layer instead of the earth's surface. The elevated ducting mechanism acts as a "waveguide" as it propagates the trapped electromagnetic energy. (Figure 2b) The effects of this type of duct are most pronounced upon airborne systems operating in the vicinity of the elevated layer.

In addition to the extended ranges possible for systems operating within either surfaced based or elevated ducts there are other important associated characteristics, such as radar holes or shadow zones, associated with ducting mechanisms which will be discussed in the tactical exploitation section of this thesis.

3. Evaporation duct

A second type of surface duct is the evaporation duct which is a very persistant ducting form that occurs immediately over the oceans surface. It is associated with the very rapid decrease in the moisture content immediately above the air/ocean interface. The evaporation duct is found to some degree nearly all of the time over oceanic areas but is characteristically shallower and weaker than the surfaced based duct associated with elevated layers. Because of the shallow nature of the evaporation duct it has neglible effect upon systems operating in the VHF/UHF portion of the spectrum. However, it does affect the propagation of electromagnetic energy in the higher EHF range of frequencies. The evaporation duct is normally 5-15 meters in depth, and as evident from table 1, would only be important for frequencies above 6 ghz.

Since this thesis deals with the effects upon operational tactical systems, which currently utilize the slightly lower VHF/UHF portion of the electromagnetic spectrum, we will consider only ducting mechanisms associated with elevated layers. This precludes further discussion of the evaporation ducting environment.

B. GEOGRAPHICAL CONSIDERATIONS OF DUCTING FREQUENCY

Surface based and elevated ducts occur as a result of the variability of the vertical temperature and water vapor distribution of the air. The synoptic conditions responsible for these conditions occur over land as well as the ocean. However, ocean ducting persistance is enhanced by the trade-winds circulation of relatively large air masses of uniform characteristics.

Because of this association with large circulation patterns, ducting mechanisms are usually rare at extremes in northern or southern latitudes but are a regular occurrence over the warmer subtropical and tropical oceans. In some important operational areas of the world such as the mid-Pacific, the eastern Mediterranean and the Indian Ocean it is not unusual for ducting conditions to persist for days or even weeks at a time.

A world wide computer analysis of upper atmospheric radiosone data was performed by Ortenburg [Ref. 2] of the frequency of ducting occurrences found in the various areas of the world. (Figure 3)

This analysis confirmed how prevalent the ducting environment is in the trade wind regions of the world.

Located between the mid-ocean pressure cells and the equatorial doldrums, this area known as the trade wind inversion region, extends to approximately 30° north and south of the equator. In this region cool moist air circulates from east to west underneath a cap of warm dry subsiding air. This is a semi-stable condition since the warm dry air effectively restricts the upward movement of the underlying cooler moist air resulting in a boundary condition of positive temperature and negative humidity lapse rates conducive to the formation of ducting mechanisms. It is this boundary which is known as the trade winds inversion and is believed to be present at least 75% of the time in all subtropical oceanic areas. Frank [Ref. 3]

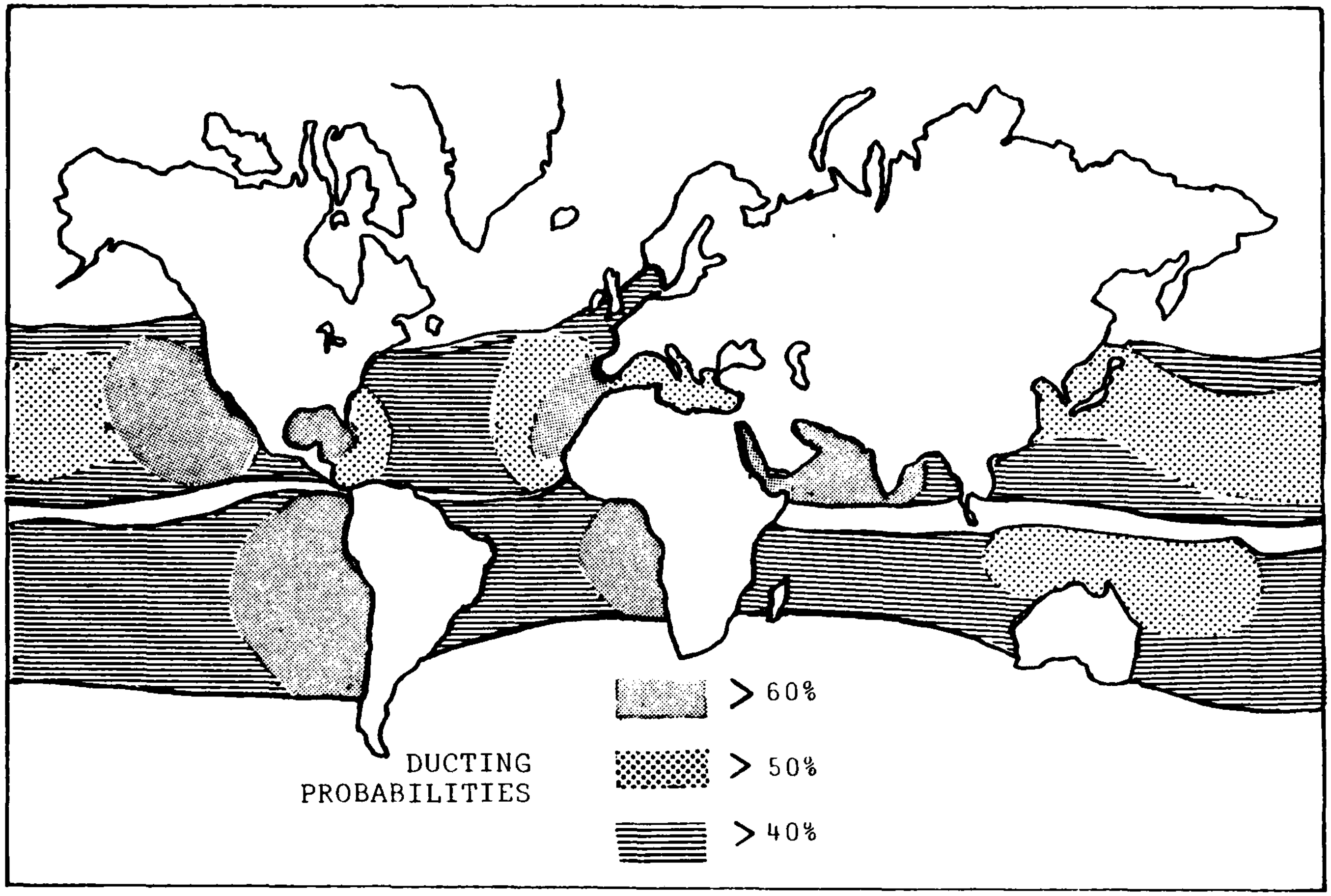

Fig. 3. SIGNIFICANT DUCTING REGIONS OF THE WORLD FROM ORTENBURG REPORT.

C. TACTICAL EXPLOITATION

The effects of the atmosphere upon electromagnetic emissions can play a significant role in determining the tactical effectiveness of a Fleet operation. Just as sonar propagation properties of the ocean influence the planning and execution of ASW operations so to must atmospheric effects be considered as an integral part of electromagnetic combat.

Surfaced based ducting produces extended detection, interception and communications ranges. Its effects also may greatly influence a sensor systems ability to collect tactical intelligence and targeting information. A dramatic example is the effect an elevated duct can have upon the operation of a task forces' airborne assets. The detection range of early warning aircraft can be greatly extended as can the effectiveness of airborne jamming assets if they are placed at an altitude that allows them to make use of ducting properties.

In addition to the signal enhancement possibilities, ducting also results in the presence of a signal "shadow zone" or coverage hole. These coverage holes occur along the top of both surfaced based and elevated layer ducts. The coverage hole is the result of the energy trapping action of the duct. The refraction condition that causes a portion of an emitters energy to be trapped within the duct results in a region that is adjacent to the duct and located opposite the emitter to be deprived of the energy that would normally penetrate this area. This region of degraded coverage extends along the length of the duct, as shown in figures 4a and 4b, causing the effectiveness of both air and shipboard systems to be constrained by the shadow zone.

Like the enhancement properties of the duct, this degradation of coverage occurs without any system indication.

Once the ducting mechanism has been profiled then an appropriate penetration altitude can be selected for exploitation. Aircraft, utilizing the shadow zone for concealment, have been able to penetrate beyond the normal detection range of shipboard and air search systems for considerable distances using the shadow zone to mask their movements.

Thus the effectiveness and survivability of mission essential assets of a task force may be enhanced if the force commander possesses a real-time knowledge of the atmosphere's affect upon the operation of his own and his adversaries systems.

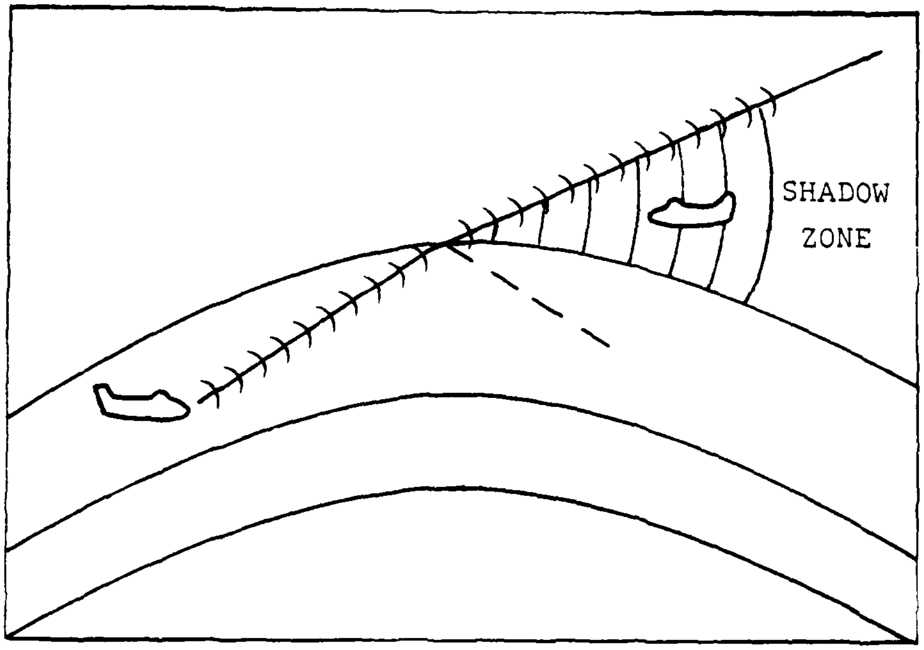

Figure 4a. AIRBORNE SYSTEM COVERAGE HOLE.

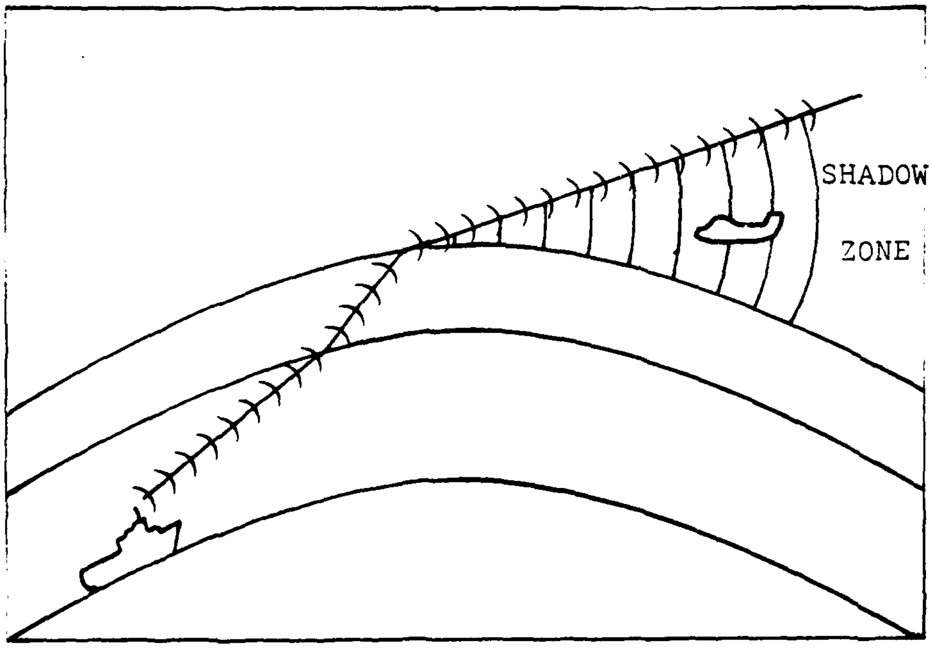

Figure 4b. SHIPBOARD SYSTEM COVERAGE HOLE.

IV. ATMOSPHERIC REFRACTIVE ASSESSMENT

A. TACTICAL REQUIREMENTS

The ability to assess and exploit propagation variations for electromagnetic combat requires more than a mere qualitative understanding of the atmosphere's effects upon electromagnetic energy. Force deployment and system utilization to detect and exploit radar system shadow zones or to extend the over-the-horizon detection range of sensor systems requires a near real-time assessment capability that is deployable with the force commander.

Radio meteorologists have provided the force commander with the diagnostic tools required to evaluate the atmosphere's refractive index. Using point source radiosonde measurements of temperature, humidity and pressure, synoptic-refractive models have been developed which can be used to describe the refractive properties of the atmosphere. These models are based on the fact that refractive conditions vary with the properties of the air mass and that certain specific vertical refractive profiles are predictably related to synoptic meteorological patterns.

B. IREPS

The Navy's current program to develope a real-time shipboard refractivity forcasting and assessment system is managed by the Naval Ocean Systems Center (NOSC), San Diego. NOSC has developed and is currently refining the Integrated Refractive Effects Prediction System (IREPS) which provides shipboard environmental data processing and graphics display capabilities.

Utilizing currently available mini and micro-computer technology an interim version of IREPS, in the form of a desktop programmable computer, has been operationally deployed aboard a select number of the carrier battle groups.

IREPS, utilizing meteorological input data consisting of the vertical distribution of air temperature and humidity, produces four types of product outputs:

1) a propagation condition summary of the existing refractive conditions for the location and date/time of the environmental input data.

2) a computer listing of the environmental input data set.

3) a coverage display profile of communications and radar systems based upon system specifications and an assessment of the environmental input data.

4) a path-loss display representative of the performance of a specified system for a given environmental data set.

A particularly interesting feature of IREPS is the coverage and path-loss displays which produce height-versus-range and path loss-versus-range plots that correspond to detection, communications, and intercept coverage areas.

The success of the interim IREPS installations have verified the importance of the need for the integation of IREPS into each battle group.

Ultimately IREPS will be installed on all Navy aircraft carriers and used as an aid in adjusting tactics to compensate for and exploit atmospheric refractive effects. Beach [Ref. 4]

A comprehensive description of IREPS and its product outputs will not be included in this thesis but is available in NOSC technical document 238, NOSC [Ref. 5]

C. PREDICTION CONSTRAINTS

Modern weapons systems dictate that the force commander adopt an operational doctrine involving tactics and procedures that require fleet units to be dispersed over a wide area of the ocean. Additionally, opposing force elements rely upon stand-off weapons systems that effectively enlarge the combined area of operations considerably. Thus in order to prosecute electromagnetic combat effectively the tactical commander must be able to assess the atmospheric effects upon systems which are located considerable distances beyond the range of his ability to gather meteorological data.

IREPS is based upon measurement of the vertical distribution of the temperature and humidity from a single location. While this data is readily obtainable by radiosonde balloon launches or microwave refractometry, it provides assessment information only for the immediate task force environment. Furthermore, tactical operating constraints will most likely limit the force commanders ability to gather meteor. data concerning the environment in the vicinity of the threat. The tactical exploitation and the prosecution of a battle plan that makes effective use of the meteorological environment is still possible however, if the IREPS assessment and evaluation capability is expanded through the integration of information about the large scale synoptic conditions over the entire region of operation.

Recognizing that radiosondes only provide measurements in the immediate vicinity of the launch location, studies are being conducted into the dynamics of large scale weather patterns and the associated refractive conditions in an effort to provide a more definitive assessment capability for Fleet operations. Investigations into such features as air mass uniformity and dynamics are leading to a general agreement in findings among radio meteorologists that over oceanic areas horizontal refractive homogeneity within a particular synoptic pattern exists for distances up to a few hundred miles from an atmospheric data measuring point.

It has also been noted that small scale perturbations within the large scale uniformity of a weather pattern do not necessarily appreciably affect the horizontal homogeneity of the refractive profile of the pattern. Glevy [Ref. 6] Such findings suggest that in instances where the large scale synoptic characteristics of the weather pattern can be accurately determined, open ocean projections of the refractive profile may be made with a greater level of confidence than is singularly possible from IREPS.

The exploratory portion of this thesis deals with the use of satellite imagery as a source of quantitative synoptic information for assessing prevailing synoptic conditions of an open ocean area.

V. PRESENTATION AND ANALYSIS OF DATA

A. THE CALIFORNIA TO HAWAII PATH

An investigation of radio-climatic features was conducted for occasions when anomalous propagation of VHF and UHF signals resulted in amateur radio communications between California and Hawaii. These occurences of trans-horizon tropospheric communications were related to the synoptic features evident in weather satellite photographs of the ducted communications path. This approach was chosen because of confidence in the predictability of the synoptic-refractive relationship and the need for a source of quantitative data designed to enhance the refractive prediction techniques for large oceanic areas.

The overwater path of interest is approximately 2500 miles long and is located within the trade winds region of the World. The latter forms a circulation pattern that plays an important part in the development of oceanic ducting mechanisms, as will be described later.

Another important synoptic feature influencing the California to Hawaii (CA-HW) path is topographic subsidence at each end which causes low-level surfaced based ducts to form and extend outward over the ocean. These ducts, commonly found along coastal areas, are not sufficient to produce communications over the entire path. However, they do contribute to heightened activity among the amateur stations at each end of the path who attempt to participate when trans-Pacific ducting conditions do occur.

Through the efforts of amateur radio operators rather complete descriptions have been obtained of instances when a strong ducting mechanism resulted in communications over the CA-HW path. These periods of ducting range from an hour to several days duration. The interest of radio amateurs in the challenge of tropospheric communications has resulted in the development, installation, and close monitoring of beacon transmitters operating in the VHF and UHF "ham bands" for any indication that the communications path is "opening". Such instances of amateur communications over the path should be of continuing interest to radio meteorologists because of the close similarity between the operating frequencies and power levels of the amateur stations and those of current military systems.

B. PATH CLIMATOLOGY

Previous occurrences of trans-Pacific amateur communications over the CA-HW path have coincided with certain climatological conditions which are well recognized features of the synoptic-refractive relationship. One condition is the presence of a strong high pressure region over a subtropical ocean area. In this case the ducting mechanism is particularly evident along the eastern and equatorward side of the pressure pattern. (Fig. 5) This region of the high frequently contains a strong atmospheric inversion which is most pronounced when decending or subsiding air blows out of the eastern end of the pattern. This subsiding air is descending from a high elevation, hence, it has lost its moisture content.

The subsiding dry air warms as it descends due to adiabatic compression. This results in the warm dry air forming a cap over the moist cool air immediately above the ocean surface. This feature, known as a trade wind inversion, causes an elevated temperature and humidity gradient and therefore a sharp decrease in the atmospheric refractive index as one ascends through the inversion layer. It is for this reason that tropospheric communications over the CA-HW path usually occur in conjunction with a stationary high pressure region off the west coast of California.

A secondary aspect of the stationary high pattern is that the pattern is tilted westward with height relative to the earth's surface. Godske, Bergeron et al [Ref. 7] As a result of this the inversion layer, and consequently the height of the ducting mechanism, is also tilted. A typically described characteristic of the CA-HW path then is that the ducting environment is located quite near the surface at the California end and is from 6000 to 8000 feet higher at the Hawaiian end. Figures 6a and 6b are IREPS

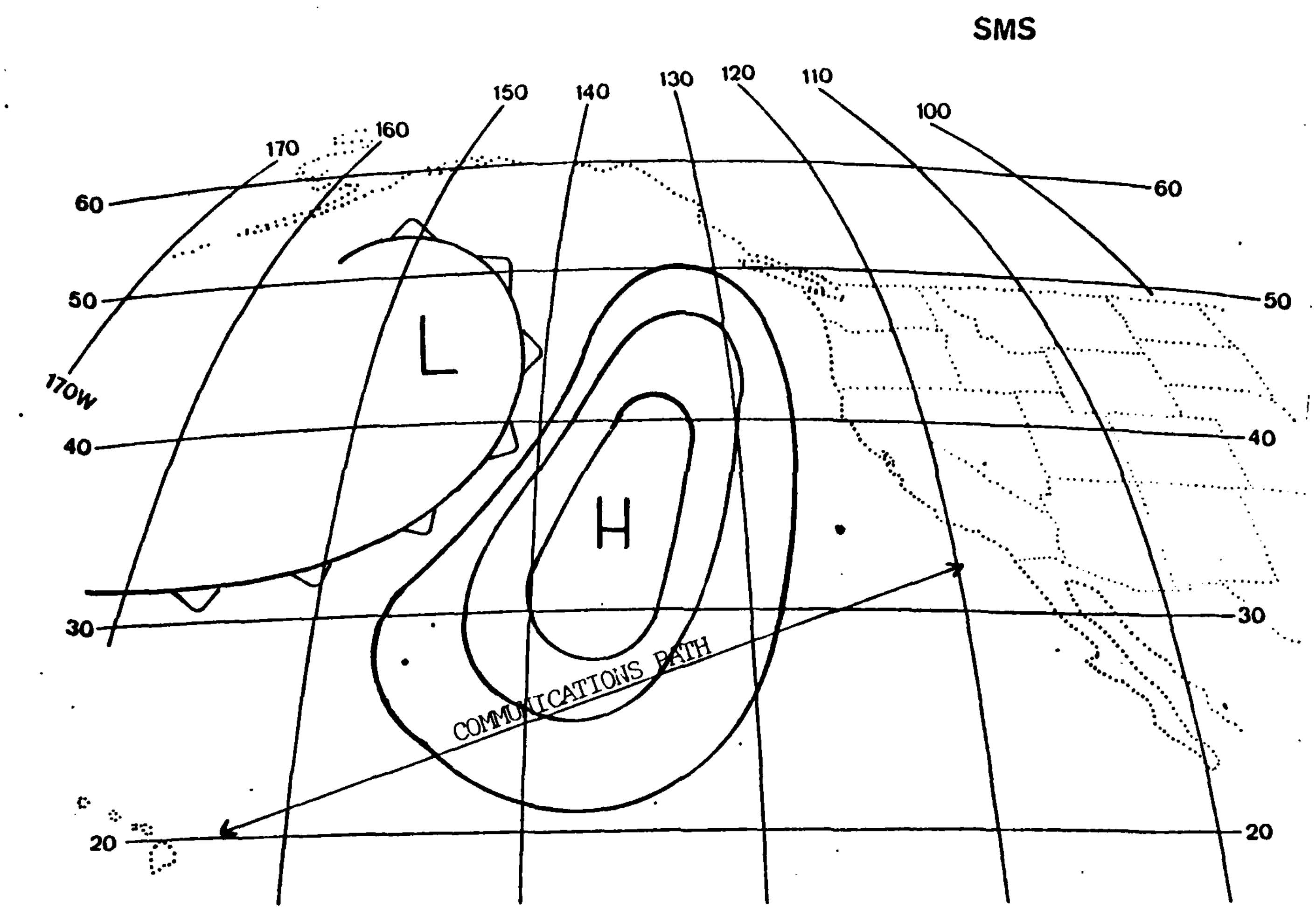

Figure 5. 19 JUL 1979. TYPICAL SYNOPTIC PATTERN PRODUCING TRANS-PACIFIC DUCTED COMMUNICATIONS.

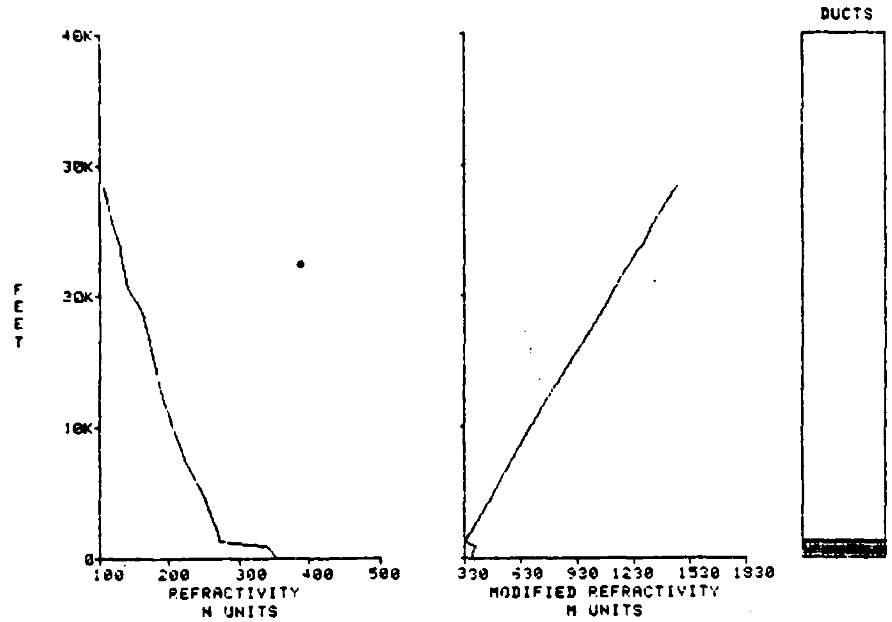

Figure 6a. IREPS PROPAGATION CONDITION SUMMARY, LOS ANGELES, 18 JULY 1979, 1200Z.

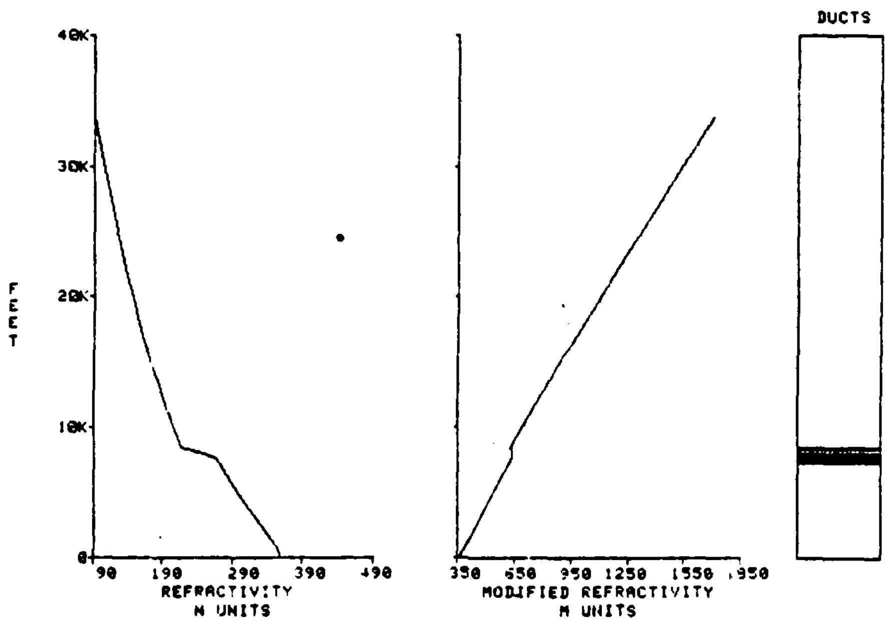

Figure 6b. IREPS PROPAGATION CONDITION SUMMARY, HONOLULU, 18 JULY 1979, 1200Z.

profiles of the environmental data sets of both the Californian and Hawaiian end of the path during the mid-July 1979 opening and graphically show this frequently noted characteristic. The strength of the inversion layer also weakens as it rises in height resulting in its eventual break up near the western end of the high pressure pattern.

Thus not only the extent and position of the high but also the topographic tilt of the inversion determines the surface area affected by the associated ducting mechanism.

These climatological understandings of the synoptic-refractive model of a sub-tropical high pressure region are necessary if one is to further make use of satellite imagery to evaluate the occurrence of ducting conditions in order to determine what factors; 1) influence the ducting environment, 2) contribute to the persistence of the ducting mechanism, and 3) caused the termination of the tropospheric communications path.

C. ANALYSIS OF SURFACE WEATHER CHARTS AND SATELLITE IMAGERY

An evaluation of satellite imagery was conducted for two periods when significant ducting conditions existed over the CA-HW path. Descriptions of these ducting occurrences, or band openings, were obtained from an article written by Overbeck [Ref. 8] and from interviews with California and Hawaiian amateur radio operators who participated in the openings.

One opening occured during the period from 17 to 21 July 1979 and resulted in the first instance of two-way communications over the CA-HW path utilizing frequencies in the 432 mhz amateur band. The second opening occured between 26 and 29 June 1976. During this period numerous contacts were logged between southern California and Hawaiian amateurs on the 144 mhz band. The July 1979 occurance is noteworthy because it was the first time two-way communications was completed on 432 mhz. The latter instance of 144 mhz communications during June of 1976 is typical of the eight other occurrences of trans-Pacific amateur communications investigated by the author or previously researched and reported upon by Frank [Ref.3] and Smith [Ref. 9].

The two instances previously indicated were chosen for discussion in this thesis because of the availability of both synoptic field and satellite imagery data for comparative evaluation. Surface weather charts and satellite imagery for the periods are shown in figures 7 - 8 and 9 - 10 respectively.

A semipermanent Northern Pacific high pressure region was present north of the ducting path during both periods as shown in the surface weather charts. (Figures 7 and 3) This resulted in prolonged subsidence and a stable trade wind inversion. Such stationary high pressure systems are

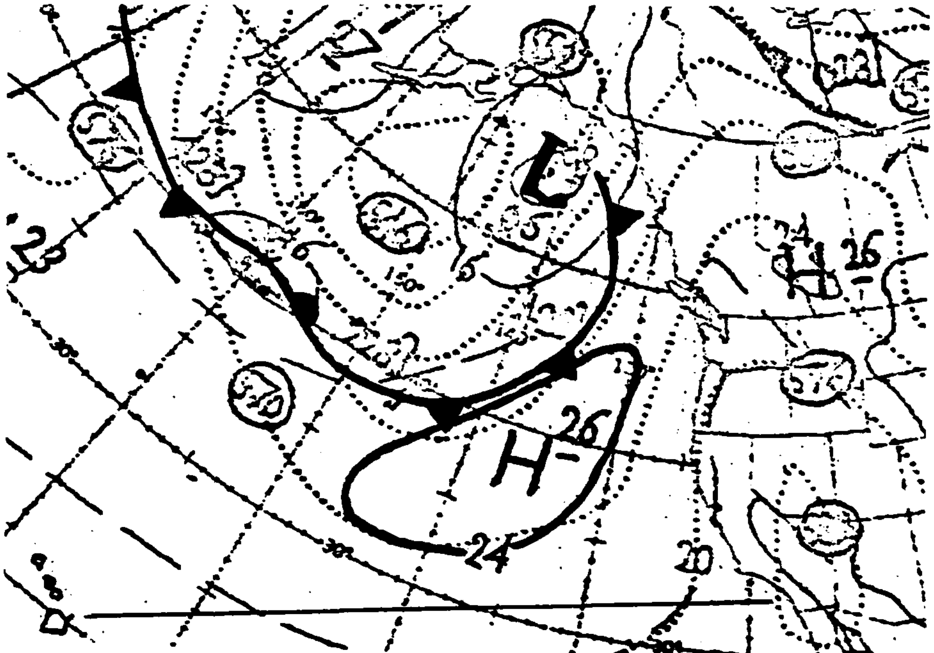

Figure 7a. SURFACE SYNOPTIC CHART - 17 JULY 1979.

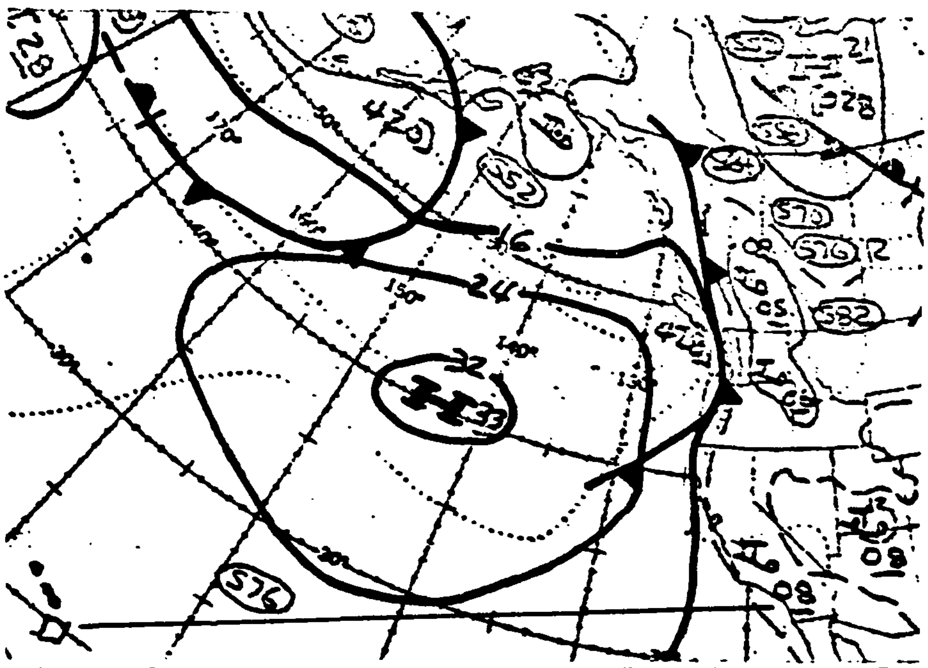

Figure 7b. SURFACE SYNOPTIC CHART - 21 JULY 1979.

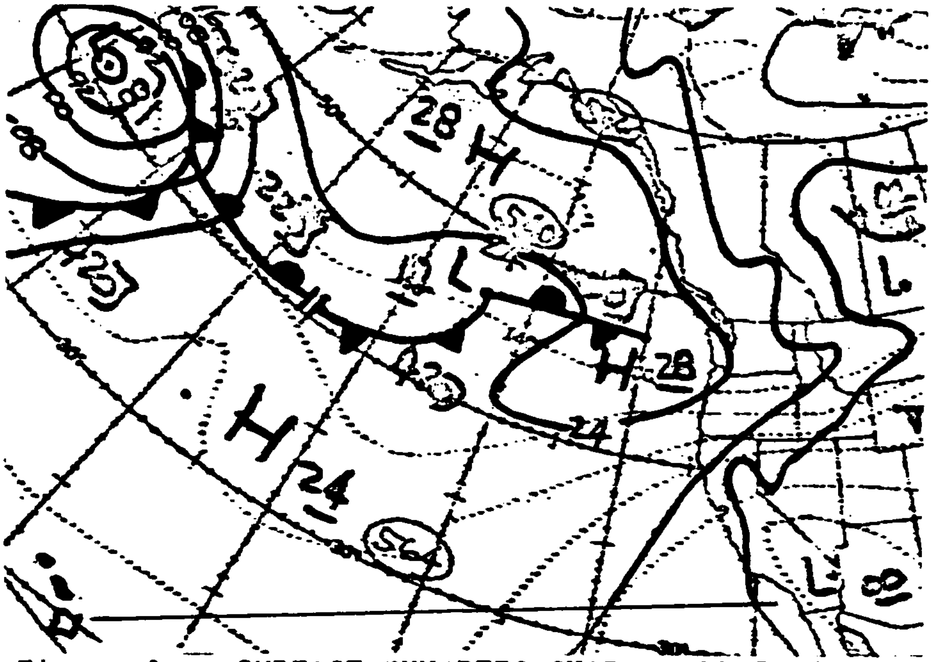

Figure 8a. SURFACE SYNOPTIC CHART - 26 JUNE 1976.

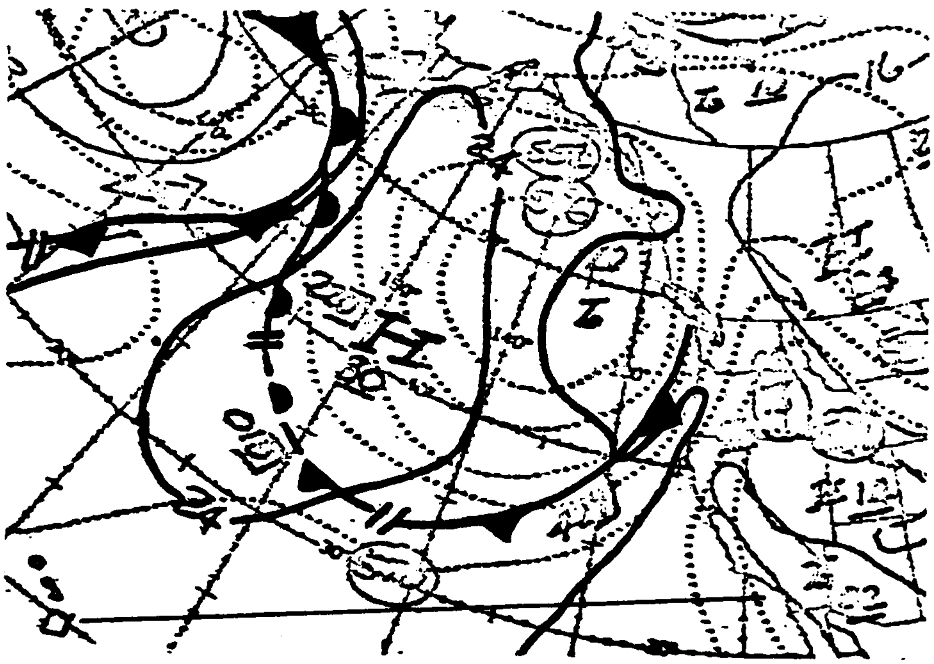

Figure 8b. SURFACE SYNOPTIC CHART - 29 JUNE 1976.

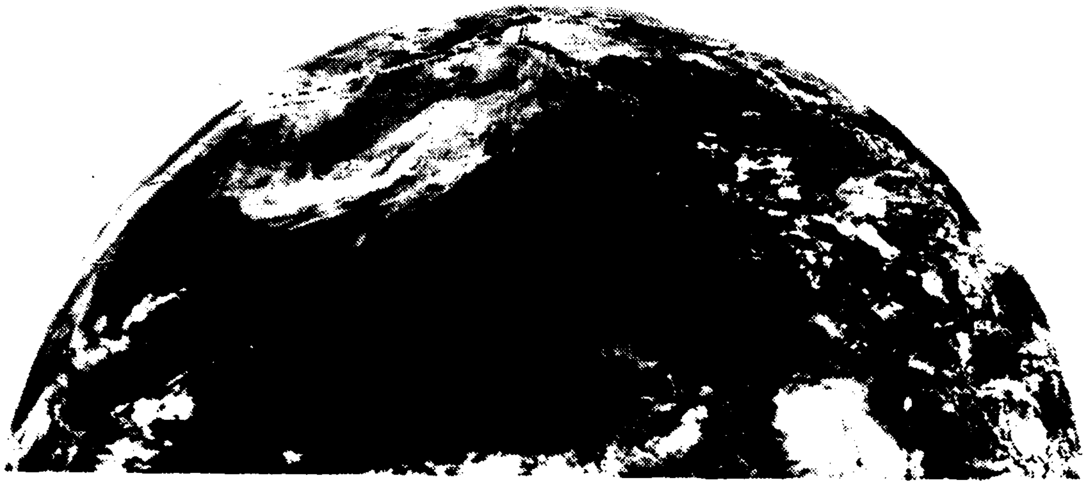

Figure 9a. GOES WEST INFRARED IMAGERY, 17 JULY 1979, 2045 GMT.

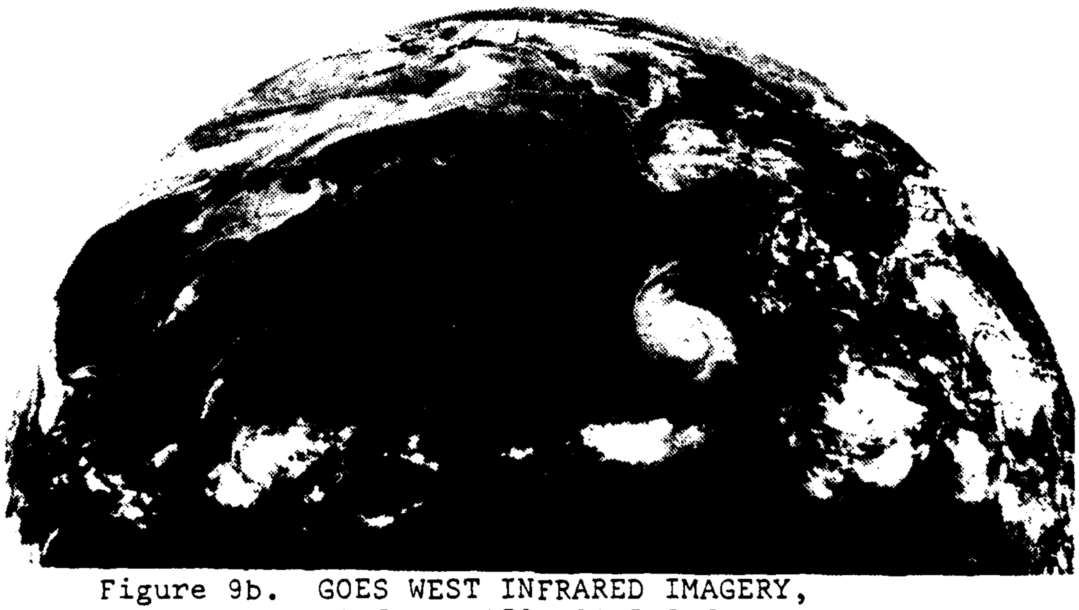

Figure 9b. GOES WEST INFRARED IMAGERY, 21 JULY 1979, 2045 GMT.

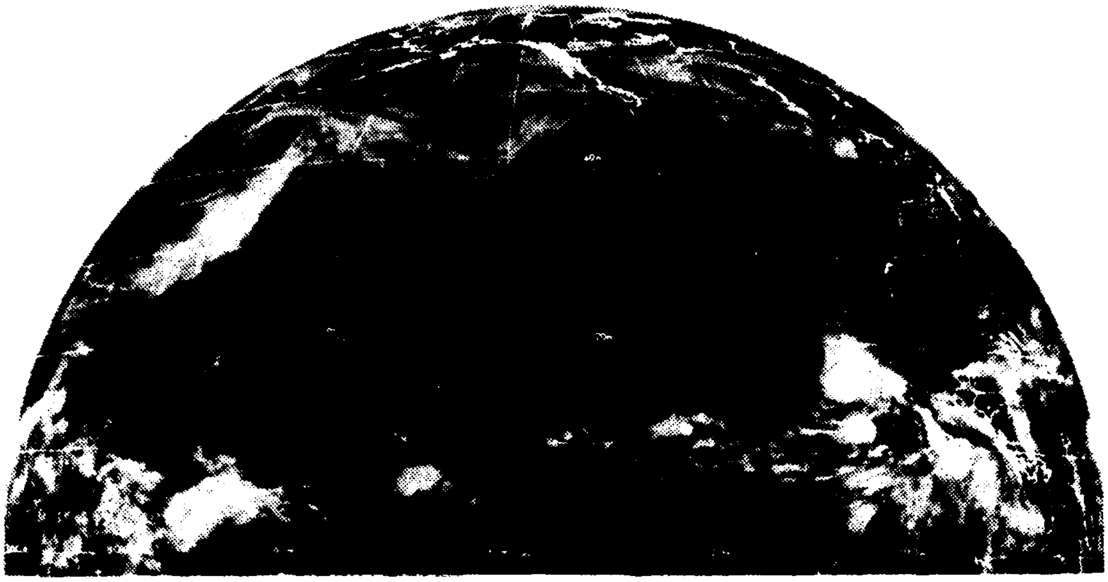

Figure 10a. GOES WEST INFRARED IMAGERY.
26 JUNE 1976, 1545 GMT.

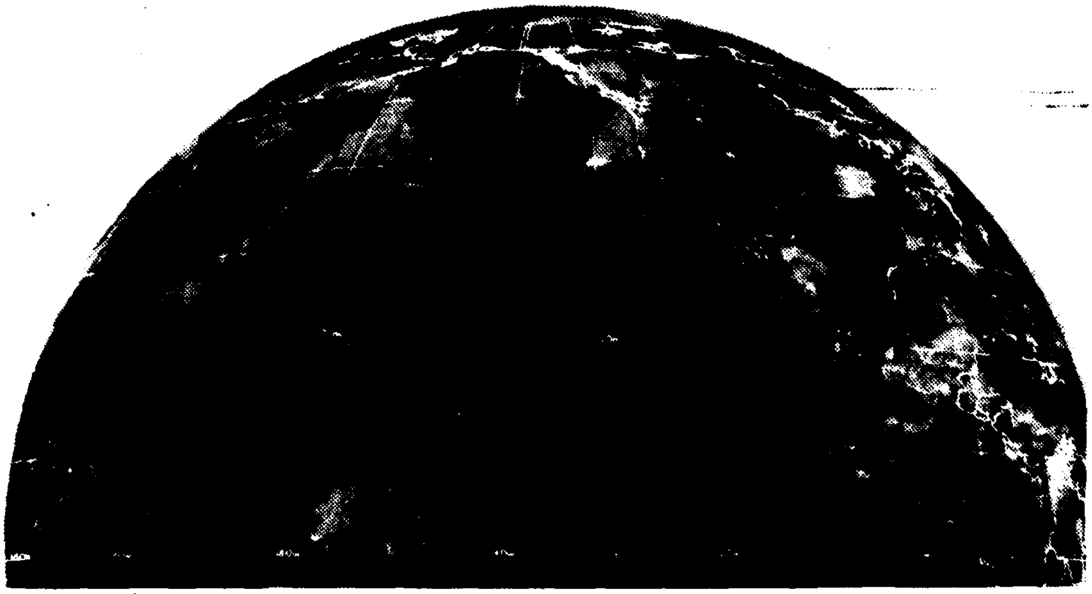

Figure 10b. GOES WEST INFRARED IMAGERY.
29 JUNE 1976, 0345 GMT.

common synoptic patterns of the area during the summer months. However, there are many instances when this semi-permanent feature does not produce an associated ducting path.

This lack of consistant ducting, even with the presence of high pressure, was examined relative to the large gradients of refractivity which produce the ducting mechanism. Since the refractivity index at the inversion layer is most sensitive to the moisture content, (Eqn 2), the absence of a pronounced moisture gradient is believed to be the primary reason why ducted communications is not a more frequent occurrence during the numerous instances when a high pressure pattern dominates the path.

We also see from the synoptic field data, (figures 7 and 8), that in addition to the existing high pressure system there was an approaching low pressure front on the western side of the high.

In addition to the high, the approaching low pressure ridge is a frequently noted synoptic feature associated with strong inversions and ducting conditions. The reason for this appears to lie in the structure of air flow patterns and the divergence/convergence associated with highs and lows.

Low level convergence, such as that associated with an approaching frontal low, leads to a more pronounced downward flow or subsidence of dry air along the stationary surface high's upper ridge. Godsky, et al.[Ref. 7] This enhanced subsidence results in increased capping of the moist air, strengthening of the inversion layer and, hence, increased refractive stratification particularly over the eastern side of the subtropical high.

Weather satellite imagery of the beginning and termination of the ducting periods, (Figures 9 and 10), show the features associated with a large stationary high pressure area and the approaching low pressure frontal wave. Another important synoptic feature discernable only from the satellite imagery is the presence of a stratus cloud deck. Stratus clouds appear in the satellite imagery as areas of gray shade and occupying the same general area as the high pressure region.

Stratus clouds are associated with the inversion layer where the warm subsiding air tops the underlying cool moist air. The strong temperature and humidity gradients associated with the inversion layer cause radiati e cooling to occur at the inversion level resulting in the formation of a relatively uniform stratus deck at the top of the underlying cool moist layer. (Figure 11) The stratus deck generally does not show appreciable vertical development and is usually less than a few hundred meters thick. Stratus clouds, however, may develop over an appreciable portion of the area capped by

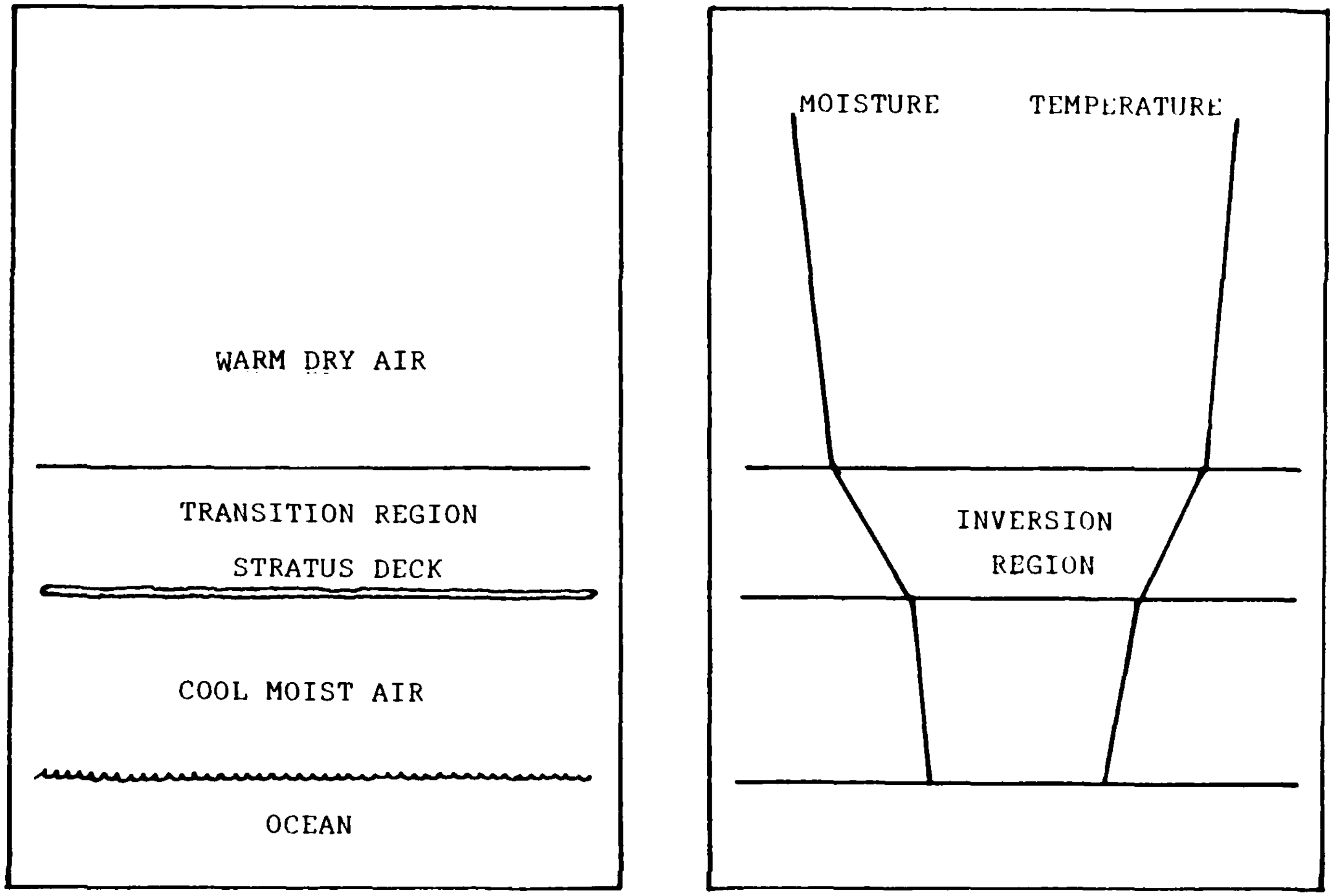

Figure 11. INVERSION LAYER PROFILES WITH STRATUS DECK.

the inversion and, presumably, visually define the region where the inversion layer is strongest.

Rigwalt and MacDonald [Ref. 10] also observed that the refractive gradients which produce a ducting mechanism were associated with the occurrence of stratus. In a study of the ducting environment between Brazil and Ascension Island they reported that elevated strong refractive index gradients were associated with regions where a uniformly developed and textured stratus deck existed.

The presence of a stratus deck does not necessarily guarantee that a critical refractive gradient exists but does provide additional visual verification of the existance of an inversion layer. Therefore, it is concluded that stratus is a better indicator of the possible existance of a ducting mechanism over the CA-HW path than just the presence of a high pressure pattern and the associated inversion layer.

During periods associated with persistent ducting, (Figures 7a and 8a), the stratus deck also remained relatively uniform and consistent in texture. The termination of the ducting path coincided with the break up of the stratus deck, (Figures 7b and 8b), reflecting a change in the synoptic features associated with the ducting environment. Thus the stratus deck is a visual indicator of the dynamical characteristics associated with the ducting mechanism over large open oceanic areas where direct meteorological data cannot be gathered.

VI. SUMMARY AND CONCLUSIONS

Effective tactical exploitation of the refractive environment requires the integration of large scale oceanic synoptic data and IREPS type predictions into a consolidated analysis profile for the operational area of concern.

Satellite imagery should be used as a readily available near real-time source of this quantative oceanic synoptic data.

Analysis of satellite imagery from the selected periods of trans-Pacific tropospheric communications identified significant synoptic features associated with the propagation path and described the discernible visual indications of the possible presence of an anomalous ducting mechanism.

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